

## **Time-resolved x-ray imaging of magnetic nanostructures driven by spin-torque**

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Spin-torque involves the transfer of angular momentum from a spin-polarized current to a ferromagnet. There is much excitement in the use of this effect for developing non-volatile, high density magnetic RAM, as well as for DC current-driven microwave oscillators. Indeed, steady-state precessional modes as well as full magnetization reversal of nanoscale magnetic elements driven by spin-torque have been observed. These observations have been via giant magnetoresistance measurements, using a reference "fixed" magnetic layer, which also serves as the spin-polarizer. Given the experimental challenges of probing thin, buried nanomagnets, the detailed magnetic configuration of the element has remained unknown.

I describe a high resolution, time-resolved x-ray microscopy technique which provided the first direct images of the nanomagnet during the switching process. Motion pictures with 200 ps time steps and 35 nm spatial resolution reveal that the process is based on the transient formation of a vortex configuration. A vortex is a magnetic pattern analogous to the wind pattern of a hurricane. It is seen that the vortex moves across the magnetic element, leaving behind a switched magnetization in its wake. I discuss a physical picture for this unexpected mechanism based on numerical modeling which successfully reproduced the behavior. The highly non-uniform magnetic configuration taken by the sample is initiated by the Oersted field, but is primarily formed by the effect of the spin-torque. Different switching mechanisms were also observed as a function of sample dimensions. These are discussed as well, and a framework which unifies the various switching modes is presented.